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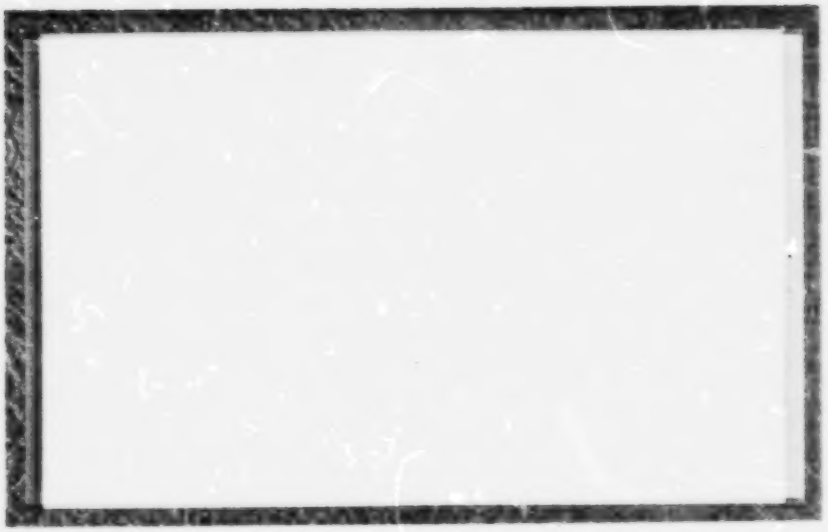

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SIMULATION AND GAMING WITH JET-SET : AN INTERCITY PASSENGER TRANSPORTATION TRAINING TOOL

by

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ABSTRACT

JET-SET is an interactive microcomputer-based system for the training of planners and managers in the intercity passenger transportation domain. It is designed as a decision-making game in a simulated multimodal and multicompany transportation market in which six transportation companies owned and managed by players or teams of players compete with one and other.

This paper presents the basic issues and objectives that guided the design of JET-SET; it describes the running of the game and the simulation program which is made of four components : an operation model, a transportation model, a fleet model and a budget model.

The current version of this simulation game operates on the APPLE IIE microcomputer or on the IBM-PC.

This paper presents a computerized system prepared for teaching individuals to operate in complex situations like the one previously summarized. The software, named JET-SET (Jeu Éducatif en Transport/Simulation for Education in Transportation), has been designed as a simulation and decision-making game to help familiarize participants to the internal dynamic forces and interactions of the intercity passenger transportation market. JET-SET, which will allow players to experiment on the effects of their decisions and that of their competitors, is intended for the specialized training of planners and managers in the intercity passenger transportation domain and for the training of students interested in this domain.

Section 1 presents the basic but essential issues that guided the design of JET-SET. Sections 2 to 4 present the objectives of the game, the way it operates and the structure of the software. In sections 5 and 6, the simulation program and in particular the transportation model are described, detailing the route choice and trip assignment procedure. Section 7 provides brief comments about some experiments with the game and about its future extension, while section 8 concludes the paper.

1. THE DECISION-MAKING PROCESS AND ITS ENVIRONMENT

As in many other industrial sectors, decision-making in an intercity passenger transportation company is characterized by :

- the multiplicity and diversity of decisions;
- the necessity to make decisions at different levels, in due consideration of various periods of time;
- the high level of interaction between all decisions;
- the necessity to work in a complex and changing environment which has direct and indirect impacts on decision making.

Figure 1 illustrates the situation. Decisions apply in the first place on the definition of a supply policy, that is the network

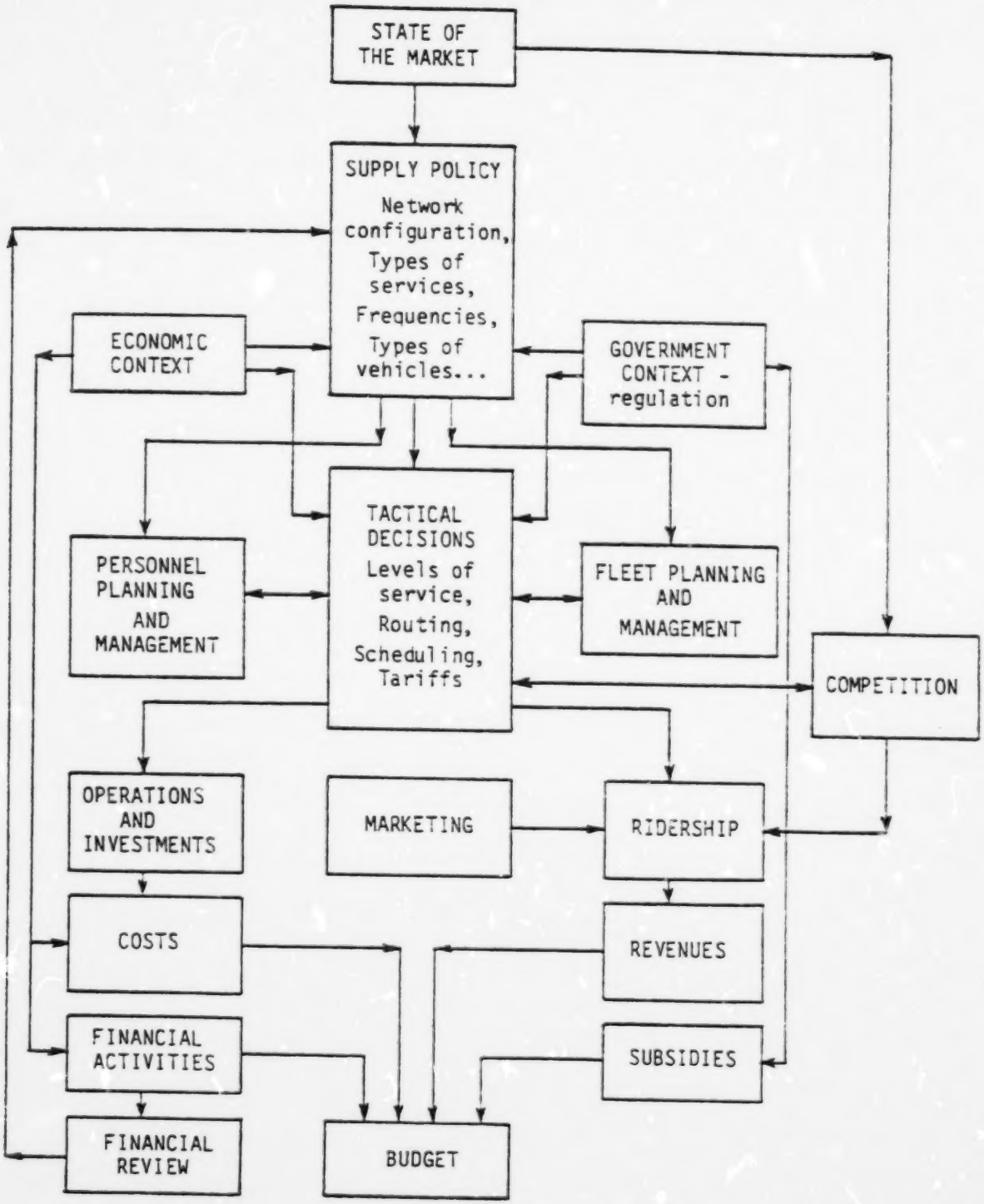

Figure 1 : **The Decision-Making Process in Intercity Passenger Transportation**

configuration, the types of services between each city pair, the frequencies, the general planning of equipment acquisition, etc. This global policy design must take into consideration the state of the market, that is the demographic trend, the transportation demand, the position of each mode and each company, etc. It should also consider the economic context (cost of energy, inflation rate, labour cost, ...), the government context (transportation policies, support to some modes in particular, regulation, ...) and the financial state of the company.

The orientations and choices adopted at this level must be taken for long, medium and short terms and must be related to the planning activities for the development of the company. This procedure will enable the company to introduce services that it desires to offer now as well as others in the coming years. Analyses are necessary at this level to plan the development or the replacement of the vehicle fleet, the hiring or training of personnel, etc.

However, it is mainly at an operational and more tactical level that questions are raised regarding the availability and allocation of human and material resources. This level of tactical decisions is the one at which the company decides in detail the level of service to offer between city pairs, and consequently organizes its multiple operations taking in consideration the seasonal, weekly and daily variations of the transportation demand. The schedules and the capacities assigned to these schedules are defined; the routing and scheduling procedures are outlined; the assignment of each vehicle category and the personnel for these services is managed; the maintenance activities are organized; the tariffs are chosen, etc. All these actions are made while taking into consideration the government's regulations, they interact with each other, and they all influence human and material resources required to ensure the services and vice versa.

Of course, when making its decisions, the company must evaluate the financial implications on the one hand and predict the possible effects on the market on the other hand. The financial implications relate to the operating costs and revenues but also to the investments required for the acquisition of new equipment. While forecasting, the company must also consider marketing strategies and competing mechanisms that rule the market behaviour.

Lastly, considering its investments, operating costs and operating revenues, the company must manage a budget which also includes other categories of revenue and expense, for example government subsidies, revenues related to sales on board of vehicles, taxes, R&D expenses, etc. In addition, the company has access to financial tools such as loans that must be planned in parallel with its investments and its obligations to balance its budget. However, these tools are limited as they are governed by the financial market (interest rates, credit limit, ...).

In order to go through this decision-making process, the company relies in part on its own historical development; in general, the evolution of its position in each market segment procures a good indication on potentially interesting adjustments of the service to be offered. The company can also use, but less frequently, information systems and performance indicators in order to account and control several components of its operating costs and revenues, to evaluate benefits and costs of its investments and to prepare more detailed forecasts.

However, apart from their own personal experience, planners and managers in the intercity passenger transportation industry (including governement managers in charge of policies and regulations) possess few tools with which to grasp the multiple and interacting effects of all their possible decisions. No method or instrument exists to analyze and forecast, in a completely integrated and detailed manner, the correlated

effects of all decisions, of the economical contingency and of the regulation on the market behaviour, on the companies productivity/competitiveness and on the financial health of these companies.

2. JET-SET : ITS PHILOSOPHY AND ITS OBJECTIVES

Decision-making in the intercity passenger transportation field thus represents a difficult task which is considered by many people to require more sensibility to the social and political context than scientific and rational considerations. Whatever, the question that remains to be answered is how to train individuals in order to help them make good decisions in such complex situations.

This question was the starting point of the research project devoted to the design and development of the JET-SET training and simulation game which considers most of the mechanisms and interactions illustrated in figure 1. Simplifications which have been made relate to the detailed management of operations; in particular, routing and scheduling matters are not examined in JET-SET. (However, a simplified notion of scheduling is implicit, and players have to take it into considerations).

The goal of the JET-SET package is to create an artificial environment with four objectives :

- To reproduce, to a great extent, the complexity of the situations in which intercity passenger transportation companies have to evolve;
- To enable the participants to make diverse and interrelated decisions as the ones encountered in practice;
- To enable the participants to experiment progressively with the effect of their decisions, the effect of those taken by their

competitors and the effect of the economic and regulative environments;

- To make the participants aware of the underlying market forces within the intercity passenger transportation arena, and particularly to the interactions between competing modes and companies, as well as to the mechanisms that determine the equilibrium between transportation supply and demand.

JET-SET can be described as a dynamic simulation model and sequential decision-making exercice. It is justified by the need for innovative teaching and learning aids for the planning and management of transport systems (Ortuzar and Willumsen, 1980).

3. RUNNING OF THE GAME

There are six transporation companies in JET-SET : one conventional train company, one rapid train company, two traditional bus companies and two air companies, one offering STOL services (Short Take Off and Landing).

Each run of the game represents one year of operation of all companies (see figure 2). At the beginning of a match, each company is in a predetermined situation : it owns a fleet of vehicles with given technico-economic characteristics (price, capacity, operating costs, life-span ...), it has a specific market share between each city pair that it serves, etc. The complete network includes seven cities, each company having a direct service between 6 of the 21 city pairs.

Each player, or team of players, owns one of these six companies and has full responsability of it. In this regard, the player is required to make several decisions concerning his company : frequency of service offered between each city pair, fares, purchases or leasing of vehicles to enlarge the fleet or to replace old vehicles, loans or debts repayments,

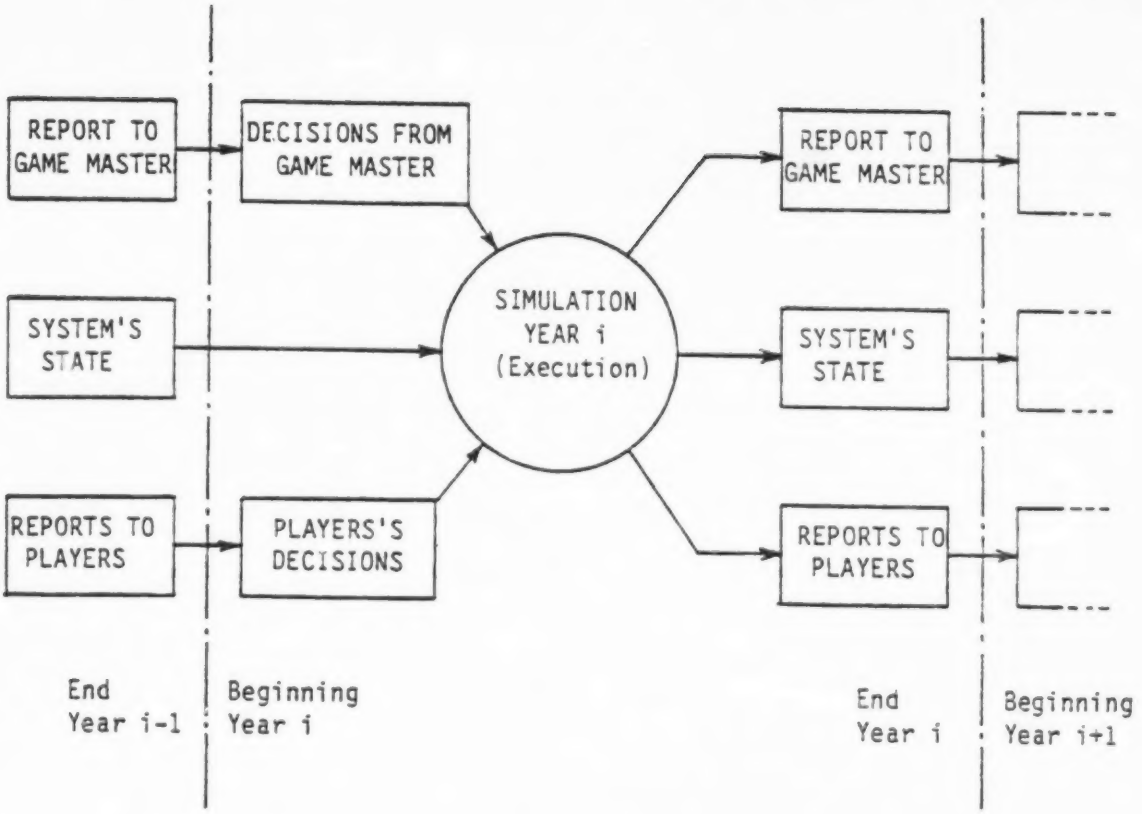

Figure 2 : Running of the game

etc. The player can also decide to initiate special projects, such as promotional campaigns or market studies. Each player must make these decisions at the beginning of each year, using the information contained in the activity report that he has received at the end of the previous year.

Some part of the information included in such a report is general data giving a general view of the whole transportation system and the economic, demographic and governmental context : population per city, interest rate, variations in salary and energy unit costs, taxation rate, subsidy rate, etc. Additional information from regulatory agencies impose constraints on permitted variations in frequencies and fares. The other part of the information contained in the activity report is private information which concerns the company : its physical operations during the year

that is terminating, the composition of the vehicle fleet, its ridership for each city pair, its operating costs and revenues, the load factors of the vehicles in operation, the costs of its investments and of its banking activities, its financial situation, its credit limit, the number of vehicles on order, etc. Additional private information is given to the players who have requested special projects. All this general and private information constitutes a means for a player to analyse the state of its company and its environment, so that this information helps him to make decisions for the following year.

A seventh character, as important as the six players, intervenes in JET-SET. This is the "game master" who plays the role of a government with economic and regulatory power, and some "extra" power such as the capability to influence the demographic context.

At the end of each year, the game master also receives a report including information on the state of the transportation network, the market shares of each company, their respective performance, etc. On the basis of this information, he will make decisions to vary some indicators such as the demographic growth rate, the salaries and energy unit costs, the government subsidy rates, the interest rate, etc. The game master also regulates the permitted variations in frequencies and fares.

The players and game master's decisions are then used as input into the computer program, which creates an evolving artificial environment, within which the six companies are simultaneously present (as well as the car which is always present in JET-SET). The program simulates the multimodal and multicompany transportation network as well as the behaviour of the users of this network. The program also simulates the companies' operation and the evolution of their vehicle fleet, and it determines their annual budget in relation to their financial state.

Each execution of the program simulates one year of activity for all the companies, representing the consequences and interactions of the players' decisions and the choices made by the game master. After the execution of the program, the companies face a new situation which corresponds to the state of the system a year later, with a new equilibrium between transportation supply and demand. New reports are handed out to the players and the game master, and so forth. A complete game covers a series of simulated years in such a manner that the evolution of each company depends directly on the decisions taken by the player that manages it but also, indirectly, on the decisions taken by other companies as well as by the game master. Each player works with the objective of gradually enhancing his decision-making capability while experimenting with the dynamic mechanisms of the market. For a detailed description of the operation and rules of the game, see Lardinois et al. [1985].

4. SOFTWARE COMPONENTS

As illustrated in figure 3, the software is composed of three major elements :

- A data bank grouping several files containing all the information which describes the state of the system at the beginning of a match, as well as during the next successive runs.
- A simulation program that solves the mathematical models which describe the relationships between all the system's variables and determine the impacts of the decisions of all players and the game master.
- An interface between the user and the data bank, that is a "user friendly" interactive program that enables an easy dialogue between the user and the software for the collection of the players' and the mater's decisions, for the updating of the data

files and for the editing of the output reports. This interactive program also allows the simulation program execution tc be controlled.

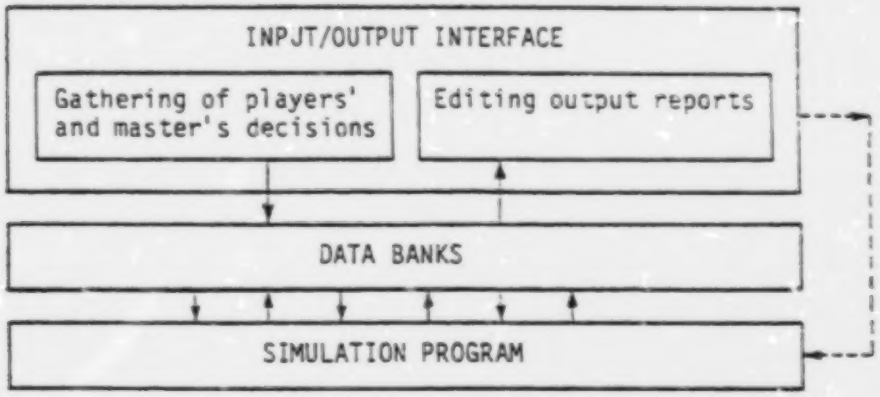

Figure 3 : Main components of the software

The software operates on the APPLE IIE microcomputer as well as on the IBM-PC (Cormier et al. [1985]).

The interface between the user and the software constitutes a key element that characterises the facility and the flexibility of utilizing JET-SET. The presentation of this interface would be too tedious in the context of this paper but the simulation program, particularly the transportation model, is detailed hereafter.

5. THE SIMULATION PROGRAM

The series of interacting operations executed in order to simulate one year of activities for all companies is schematized in figure 4. This simulation program includes four major components.

The operation model is the simplest of all four. Using the technico-economic characteristics of vehicles and the offered levels of

service, it accounts for the physical operations of the companies and evaluates their costs. It should be noted that for similar services from one year to another, these costs can vary as functions of the energy and manpower unit costs.

The transportation model, detailed in the following section, is the heart of the program. It simulates the complete network, the transportation demand, and the behaviour of passengers on the network. Outputs of this transportation model are the ridership of each company between each city pair, the vehicle loadfactors, the detailed market structure and the operating revenues.

The vehicle fleet model has four major functions. The first function is to proceed to the annual adjustment of each vehicle fleet, including the aging of all vehicles, the shelving of the vehicles that attained the retiring age, and the introduction of new purchased or rented vehicles in the fleet; note that the acquisition of new vehicles includes those that were ordered previously but for which the delivery was delayed. The second function of the fleet model is to verify the compatibility between the fleet size and the offered services : if a company does not have a sufficient number of vehicles to ensure the services that if offers (the required number of vehicles is based on hypothesis regarding the daily peak period of the transportation demand), the program automatically applies the "imposed leases" policy, forcing the company to lease additional vehicles with a financial penalty. The third function is to update the credit limit of the companies on the assumption that the banks determine these limits as a function of the value of the fleets. The fourth function is the registering of the costs of all purchases and leases of vehicles, as well as the amortization which is calculated over the vehicles life-span.

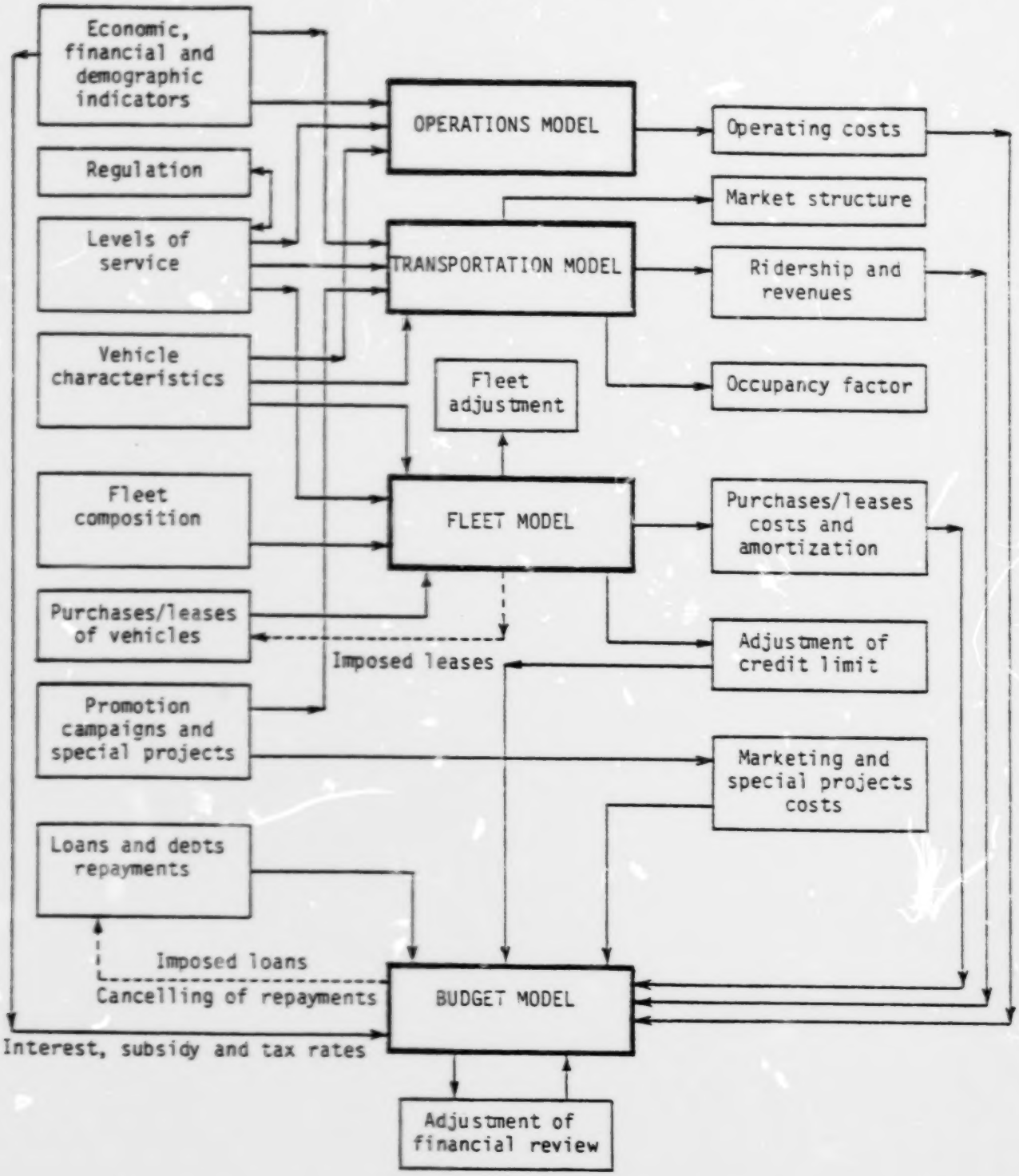

Figure 4 : Structure of the simulation program.

The budget model simulates the financial activities of each company at the beginning and at the end of each year. At the beginning of the year, when companies proceed with purchases, leases, loans and/or debt repayments, the program verifies if the companies are capable of doing such operations considering their financial situation; if it is not the case, the program will impose additional loans on some companies (at a higher rate than the regular loan rate) and/or postpone repayments. This"imposed loan" rate also applies to companies that want to borrow beyond their credit limit. The program is then used to prepare the budget of each company at the end of a year. All other costs and revenues are then assembled : operating costs, interest to pay, marketing campaigns and special project costs, operating revenues, government subsidies and interests received; the taxes to pay are computed (after deduction of amortization) and companies that do not dispose of sufficient financial resources to pay all the expenses are forced again to make an "imposed loan" and/or cancel repayments.

6. THE TRANSPORTATION MODEL

The transportation model includes two sub-models (see figure 5) : a demand model which determines the transportation demand between each city pair, and a route choice and trip assignment model which simulates the behaviour of passengers on the network while considering the restrictions imposed by the offered capacities.

The demand model and the route choice component of the second model have mathematical formulations that originate from the linear log forms of total demand models and market share models discussed by Gaudry and Wills [1977]. The essential difference relies on the replacement of the concept of "mode choice" by the one of "route choice". (This subsitution and the specific data characterizing the particular configuration of our network required adjustment to the parameters estimated by Gaudry & Wills).

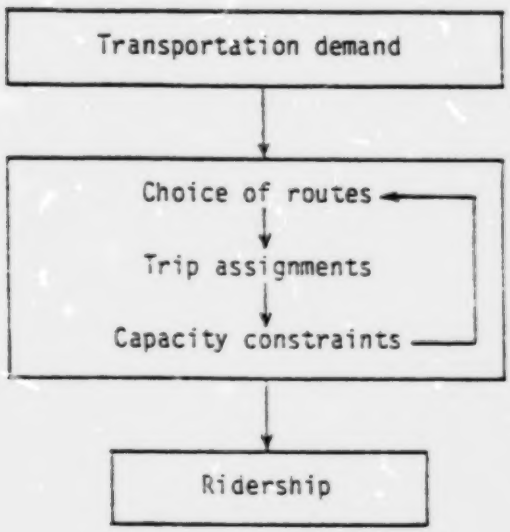

Figure 5 : Transportation Model's Structure

6.1 The demand Model

The transportation demand T_{ij} between two cities i and j is estimated with a gravity model that has the following form :

$$T_{ij} = \alpha_0 \, (P_i \, P_j)^{\alpha_1} \, L_{ij}^{\alpha_2} \, S_{ij}^{\alpha_3} \qquad (1)$$

with α_0, α_1, α_2 and $\alpha_3 > 0$

where α_0, α_1, α_2, and α_3 are parameters, P_i and P_j are the populations of cities i and j, L_{ij} is the linguistic index that measures the linguistic homogeneity of cities i and j (this index is an important explanatory variable for the transportation demand between cities of different countries or in bilingual regions such as the Province of Québec, Canada), and S_{ij} is an aggregated measure of the level of service offered between i and j, including a cost dimension. This measure is defined as follows :

$$S_{ij} = \sum_{k \in \Lambda^*_{ij}} U_{ijk}$$

$$U_{ijk} = Z_{ijk} \; C_{ijk}^{\beta_1} \; D_{ijk}^{\beta_2} \; F_{ijk}^{\beta_3} \qquad (2)$$

$$\text{with } \Lambda^*_{ij} \subset \Lambda_{ij}; \quad \beta_1, \beta_2 > 0; \; \beta_3 < 0$$

where U_{ijk} is defined as the utility or attractiveness of the path k between i and j, Λ_{ij} is the set of all "possible" paths k between i and j, Λ^*_{ij} is the sub-set of four paths that have the greatest utilities, C_{ijk} is the transportation cost between i and j by the path k , D_{ijk} is the travelling time characterizing the same path, F_{ijk} is the frequency of service on that same path, and β_1, β_2, β_3 are three parameters determining the utility elasticities regarding cost, time and frequency. Z_{ijk} is a constant which characterizes the company (or the companies) serving the path (i,j,k). The measure S_{ij} is defined over the subset Λ^*_{ij} in order to be based on a common scale for all city pairs (this subset could be defined in a different way).

It should be understood that "possible" paths are the ones that satisfy certain criteria of plausibility; in particular, due to the specific configuration of our network, all paths that require more than one transfer from a service to another are excluded, but we include all attractive paths that require one transfer at an intermediate city, for example from i to m using company X, then from m to j using company Y. For such a composite path, the cost C_{ijk} is equal to the sum of the fares associated with the two direct services (arcs) that compose the path, plus a transfer cost. Similarly, the time D_{ijk} is the sum of the travelling times associated with those two arcs, plus a transfer and a waiting time from one service to the other. The frequency F_{ijk} is defined as the smallest frequency of those associated with the two arcs that compose the path. Note also that in every case (direct and composite paths), D_{ijk} always includes access and egress times. There is a total of over 400 direct and composite paths considered throughout our network of 21 city pairs.

In order to avoid an unrealistic increase of the demand T_{ij} when companies raise very significantly the "attractiveness" of their services, the gravity relation (1) has been restricted asymptotically for large increases of S_{ij}.

6.2 Route Choice and Trip Assignment Model

Supposing that there are no capacity constraints, the transportation demand T_{ijk} related to each possible path k between two cities i and j is presented in the following relation :

$$T_{ijk} = (U_{ijk}/U_{ij})\ T_{ij} \qquad (3)$$

$$\text{with } U_{ij} = \sum_{k \in \Lambda_{ij}} U_{ijk}$$

where U_{ij} is defined as the "aggregated utility" of the set of possible paths to travel between i and j. (U_{ijk}, T_{ij} and Λ_{ij} have been defined in section 6.1).

It should be noted that if a company (or the companies) operating on a path k between i and j reduces considerably its tariff, the utility U_{ijk} of that path can become very large, to such an extent that the company can dominate almost the whole market between i and j (at the limit, in JET-SET, a company can offer some free services); such a situation, even though not probable, is not impossible. On the other hand, if the frequency of service is augmented considerably for one reason or another, there is a limit to the attractiveness of such an increase on the public; consequently, the relation (2) that defines the utility U_{ijk} has been restricted asymptotically for all large increases of frequency F_{ijk}.

Equation (3) solves the problem of simulating the route choice when we suppose that there are no capacity constraints. It expresses that travellers try to utilize possible paths in proportion of their respective utilities. The transportation demand d_a on each arc a of the network is presented in the following assignment formulation:

$$d_a = \sum_{ijk} T_{ijk} \; \Theta^a_{ijk} \qquad (4)$$

where Θ^a_{ijk} = 1 or 0 depending if the arc a belongs or not to the path k between i and j. This assignment procedure does not account for capacity constraints $d_a \leq \rho_a$, where ρ_a represents the offered capacity on arc a (the value of ρ_a is determined by the offered frequencies). In other words, this procedure does not account for the fact that some passengers can be turned down due to lack of space on the arcs that compose the path that they want to use. To solve this problem, we utilize a route choice and trip assignment procedure that is iterative and that can be summarized as follows :

- **Step 0** : For each arc a, v_a = accepted volume on arc a = 0.

- **Step 1** : Knowing the demands T_{ij}, we simulate the route choice (equation (3)) and we assign the resulting flows T_{ijk} on the network (equation (4)), thus obtaining values d_a of the "additional" demands. The "potential" demand assigned on each arc a is $D_a = v_a + d_a$.

- **Step 2** : On each arc a where the potential demand D_a is greater than the capacity ρ_a, we determine the proportion of the additional demand d_a that is excessive. This proportion is $f_a = (D_a - \rho_a)/d_a = (D_a - \rho_a)/(D_a - v_a)$. For the arcs where $D_a \leq \rho_a$, let $f_a = 0$. Note that the arcs which represent the automobile mode are always characterized by $f_a = 0$ since there are no capacity constraints on such arcs.

- **Step 3** : If $f_a = 0$ for all arcs a, stop the algorithm : the potential demand D_a on each arc a is the demand accepted on that arc. If there is at least one arc a such that $f_a \neq 0$, go to step 4.

- **Step 4** : We make the hypothesis that the probability to be rejected on an arc is the same for all travellers that want to use that arc, whatever path (i,j,k) each traveller wishes to use. This hypothesis enables us to calculate the number of travellers E^a_{ijk} on a path (i,j,k)

that are in excess on that path due to a lack of capacity on the arc a; we have: $E^a_{ijk} = T_{ijk}\ f_a\ \Theta^a_{ijk}$.

- **Step 5** : We determine the number of travellers E_{ijk} exceeding the capacity of each path (i,j,k). If this path is composed of two arcs a and b (we suppose that any "possible" path never includes more than two arcs), we have :

$$E_{ijk} = \text{Max}\ (E^a_{ijk};\ E^b_{ijk}) = T_{ijk}\ \text{Max}\ (f_a; f_b) \qquad (5)$$

because if the arcs a and b take on $T_{ijk} - E^a_{ijk}$ and $T_{ijk} - E^b_{ijk}$ respectively, this means that together they take on a number of passengers equal to $\text{Min}\ (T_{ijk} - E^a_{ijk};\ T_{ijk} - E^b_{ijk}) = T_{ijk} - \text{Max}\ (E^a_{ijk};\ E^b_{ijk})$. Obviously, if the path is composed of a single arc a, we have $E_{ijk} = E^a_{ijk}$.

- **Step 6** : On each path, passengers are rejected when in excess. We obtain the flow v_a accepted on each arc a :

$$v_a = D_a - \sum_{ijk} E_{ijk}\ \Theta^a_{ijk} \qquad (6)$$

The transportation demand that "exceeds" between each city pair is given by $E_{ij} = \sum_{k \in \Lambda_{ij}} E_{ijk}$. This "exceeding" demand is a demand that needs to be redistributed in the network after eliminating all paths including arcs that are saturated, i.e. arcs where the capacities ρ_a are exactly attained (The proof that there is at least one such arc is included in the proof of convergence below). After those eliminations, we repeat all the procedure starting with step 1 where we make $T_{ij} = E_{ij}$, and so on.

Convergence of the algorithm

To prove the convergence of this algorithm, we have to prove that there always comes a time when, at step 3, $D_a < \rho_a$, i.e. $f_a = 0$, for all

arcs a that have not been eliminated. To do so, it is sufficient to prove that, at each step 6, there is at least one arc which is eliminated, so that at the limit the only arcs that remains in the network are "automobile arcs" for which $f_a = 0$ remains always true. If the capacities are sufficiently large enough, this extreme situation is never reached and the algorithm stops before, but if it is not the case, this extreme situation always occurs and the last exceeding demand is diverted to "automobile arcs". In conclusion, we have to prove that, at step 6, there is always at least one arc a on which the offered capacity is exactly reached, after substracting all exceeding flows. The demonstration follows.

Among all the arcs on which there are exceeding flows (see step 2), there is always an arc a such that $f_a \geq f_e$ for any arc e. For that arc a, we have (see equation (5)) $E_{ijk} = E^a_{ijk} = T_{ijk}\ f_a$ for any path (ijk) including that arc. Equation (6) becomes $v_a = D_a - \sum_{ijk} T_{ijk}\ f_a\ \theta^a_{ijk} = D_a - f_a \sum_{ijk} T_{ijk}\ \theta^a_{ijk}$. Thus, with equation (4) and the definition of f_a, we have $v_a = D_a - f_a\ d_a = \rho_a$.

Note

Our route choice and trip assignment procedure suppose that, at each iteration, the exceeding demand is redistributed among all available (non saturated) paths, including the automobile mode. It would be easy to modify the algorithm so that travellers who do not find place on the offered public services (rail, bus, air or a combination) would decide not to travel at all.

7. EXPERIMENTATION AND FUTURE EXTENSION

A preliminary version of the program was run experimentally during the fall of 1984 at the George A. Scott Institute of Transport Canada during a senior transportation management course. This first trial was

excellent although the program presented various weaknesses at that time. An new version was tested in 1985 by the same institute as well as by some other organisms. All transportation professionnals that participated in these experiments were in general very satisfied with the technical and didactic qualities of the system. We thus decided to make the software publicly available, and various organisms from Canada ans U.S.A. actually decided to get this first "final" version.

As a consequence, the work that we realized until now made evident the great potential of further research in this direction : they pointed out the fact that, using the scientific qualities of transportation models together with the didactic capabilities of micro-computers, tools like JET-SET correspond to a real need for teaching and learning aids which enable people to develop a comprehensive understanding of complex dynamic systems such as those in the intercity transportation field.

Thus we now intend to develop an extended and more flexible version, JET-SET/2, so as to improve its realism and its training capability and to use it as a testing-bench for research and analysis. This new version should, among other things, offer the possibility to consider different game situations as well as the possibility to introduce different levels of detail and complexity.

8. CONCLUSION

The multiplicity and diversity of decisions to be made in order to plan and manage intercity passenger transportation systems render the decision-makers' task extremely arduous, especially as the effects of decisions interact between each other. This complex process within any company is a continuous and iterative process that repeats itself in a market environment determined by the strategies of other companies and/or other modes, as well as by the demographic, economic and governemental context.

The computerized simulation/decision-making game JET-SET presented in this paper enables the learning of these complex and dynamic situations that characterize the intercity passenger transportation industry. It is aimed at training transportation planners and managers, as well as students interested in this area.

In a context where these planners and managers do not have any choice but to enhance the competiveness and productivity of their company, the use of such simulation techniques and training tools seems very suitable and desirable. This applies equally in a governmental context where there is a requirement for deep knowledge of the transportation market in order to generate adequate policies.

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